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Review article

A review of biomechanics of the shoulder and biomechanical concepts of rotator cuff repair

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Abstract

In this article, we describe the basic knowledge about shoulder biomechanics, which is thought to be useful for surgeons. Some clinical reports have described that the excellent outcome after cuff repair without acromioplasty and a limited acromioplasty might be enough for subacromial decompression. It was biomechanically demonstrated that a 10-mm medial shift of the tendon repair site has a minimum effect on biomechanics. Many biomechanical studies reported that the transosseous equivalent repair was superior to other techniques, although the tendon may lose its inherent elasticity. We herein introduce our recent experiment data and latest information on biomechanics.

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Keywords: biomechanics; concavity-compression effect; medial shift; transosseous equivalent repair

Introduction

Recently, it has been widely recognized that evidence-based medicine (EBM) is important when providing medical care. It is the idea that diagnosis or treatment should be done based not on the doctors' personal clinical experiences but on medical and scientific objective evidence. Thus, the idea of EBM is important even in the field of orthopaedic surgery. A number of studies and experiments were carried out to obtain the objective evidence in this field. Biomechanics is one of the methods used to obtain the objective evidence. Although biomechanics is a relatively older method, biomechanical experiments are performed using the latest measurement device and analysis software. In this article, we describe the basic knowledge about shoulder biomechanics, which is thought to be useful for shoulder surgeons to perform surgeries, and introduce our recent experiment data and latest

biomechanics information. This paper was presented at the 1st Congress of Asia-Pacific Knee, Arthroscopy and Sports Medicine Society in April 2014.

Biomechanics of the shoulder

In this section, we explain shoulder biomechanics focusing on the rotator cuff muscles, and describe the concept of rotator cuff repair in the next section. The rotator cuff muscles work not only as a motion actuator (abduction or external and internal rotations) but also as a shoulder stabilizer. At the end range of shoulder motion (abduction and maximum external rotation), the capsuloligamentous structures such as the inferior glenohumeral ligament contribute to shoulder stability. In the mid-range of shoulder motion, because the capsuloligamentous structures are lax, shoulder stability is mainly provided by the glenoid concavity and the compressive force generated by the rotator cuff muscles (concavity–compression effect).¹ The glenoid depth is very shallow but the labrum makes the glenoid depth deeper by 50%.² The concavity–compression effect depends on both the depth of the glenoid and the compression force. To confirm this, we

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performed a simple biomechanical experiment using a synthetic bone (Fig. 1).³ Three sizes of the depth of the concavity were created in the synthetic bone: 0 mm (flat), 3 mm, and 6 mm (Fig. 2). Applying the three kinds of the compressive load (0 N, 50 N, and 100 N), the peak translational force was measured by the load cell. A compressive force was constantly applied to the metal humeral head by a low-friction pneumatic cylinder to keep the metal humeral head centred in the concavity. The testing apparatus consisted of a six-degrees-of-freedom load cell (model 45E15A-E24ES-A; JR3, Woodland, CA, USA) with which the compressive force could be monitored. The surface of the synthetic bone was lubricated with grease to reduce the friction between the synthetic bone and the metal humeral head. As a result, the peak translational force increased with the increase of the compressive load and with the increase in depth (Fig. 3). It was demonstrated that the deeper the glenoid depth or the greater the compressive load, the greater the concavity–compression effect. Our data reflects the stability provided by the bony contour of the glenoid socket and the compressive force. It is still unclear how this concavity–compression effect is related to *in vivo* glenohumeral contact pressure under physiological loading conditions. This study is a biomechanical experiment using a synthetic bone, which is different from the actual *in vivo* condition. Our data showed the mechanical effect of the compression force with different glenoid concavities on shoulder stability. During shoulder motion, both the anterior (subscapularis muscle) and posterior (infraspinatus and teres minor muscles) rotators contribute to keep the humeral head in the glenoid socket. Considering that the cross-sectional areas

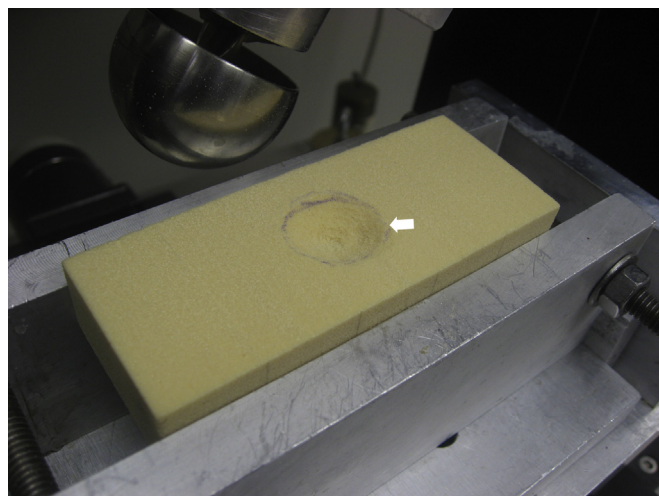


Fig. 2. Concavity created in the synthetic bone. This image shows a 6-mm depth (arrow).

of the anterior and posterior rotators are approximately equal,⁴ it is understandable that the torques generated by these groups are balanced and represent a force couple that resists humeral head translation.

Concept of the rotator cuff repair

The aetiology of rotator cuff tear is multifactorial, and has been attributed to both extrinsic (subacromial impingement) and intrinsic (alterations in biology, mechanical properties,

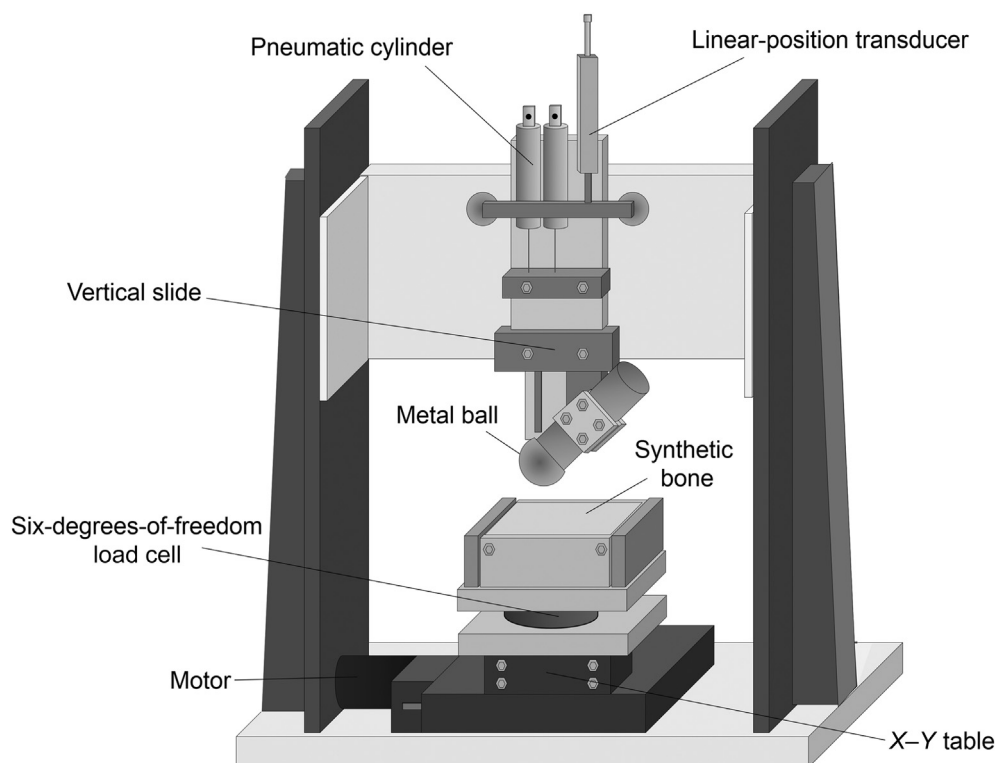


Fig. 1. Custom mechanical testing device. The metal ball simulating the humeral head was compressed to the synthetic bone.

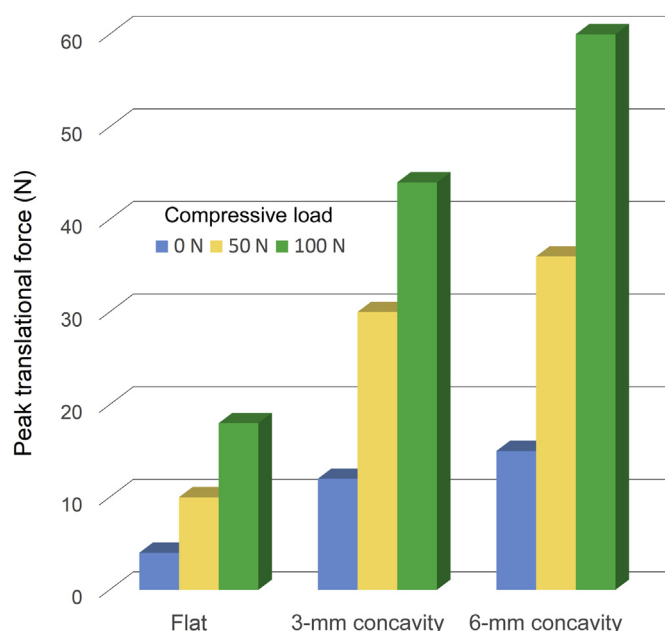


Fig. 3. Graph showing the relationship between the peak translational force and the concavity or compressive load. As the concavity becomes deeper or the compressive load becomes greater, a greater translational force is required. A 0-N compressive force means that there was no additional load to the metal humeral head but the weight of the metal humeral head and the attachment device were applied.

and vascularity) mechanisms. Some studies have suggested that the intrinsic pathological conditions play a role in the spectrum of rotator cuff disease. We, in a cadaveric study,⁵ demonstrated that nonpathological contact beneath the coracoacromial arch occurred in normal shoulders without pain and concluded that the contact phenomenon between the coracoacromial arch and the rotator cuff tendons was not a pathological but a physiological condition. Recently, performing acromioplasty with a rotator cuff repair has become a subject of controversy. There have been some clinical reports describing the excellent outcome after cuff repair without acromioplasty.^{6–8} According to the 2011 guidelines published by the American Academy of Orthopaedic Surgeons,⁹ “routine acromioplasty is not required at the time of rotator cuff repair.” A biomechanical study by Denard et al¹⁰ demonstrated that a limited acromioplasty (3 mm in thickness) might be enough for decompression while preserving the coracoacromial ligament. Because of variations in the distance between the undersurface of the acromion and the cuff surface, the level of acromioplasty should be decided during surgery on a patient-specific level. For example, in our clinical practice, before performing acromioplasty, we arthroscopically confirm the location and degree of impingement between the undersurface of the acromion and the cuff tendons moving the upper extremity as we perform the Neer’s or Hawkins’ impingement sign, which is not a quantitative evaluation method. Based on the initial findings, we then decide how much acromioplasty should be done. Using this approach, we are able to perform the least amount of acromioplasty necessary to avoid impingement.

It is ideal during the rotator cuff repair to reconstruct the function and anatomy of the rotator cuff tendons. However, when a tear is large, it may sometimes be difficult to bring the torn edges back to the original insertion site of the greater tuberosity. In those cases, a medial shift of the insertion site of the cuff tendon is one of the surgical options. Cofield¹¹ introduced the medial shift of the repair site as one of the surgical options for a large tear. Liu et al,¹² in a biomechanical study carried out in the Mayo Clinic (Rochester, MN, USA), demonstrated that 10 mm of medial shift of the repair site had a minimum effect on the moment arm during elevation. In addition, it is speculated that shoulder motion would be affected by a medial shift of the repair site. This is the reason why we performed the following biomechanical study using fresh frozen cadavers. Our biomechanical study¹³ demonstrated that significant restriction of joint motion did not occur when a bony trough was created within 10 mm medial to the footprint of the cuff tendons, although all motions were restricted to some degree by the medial shift. A medial shift (3 mm, 10 mm, and 17 mm) significantly reduced the range of abduction, which was restricted by $4^\circ \pm 5^\circ$, $17^\circ \pm 12^\circ$, and $31^\circ \pm 11^\circ$ compared with that of the intact shoulder (3 mm, 10 mm, and 17 mm). The more medially the insertion site of the tendon is shifted, the earlier the physiological internal impingement occurs and the less the abduction is achieved (Fig. 4). The range of internal rotation was restricted by 4 ± 4 , 7 ± 7 , and 11 ± 7 , external rotation by 8 ± 5 , 11 ± 6 , and 18 ± 7 , internal rotation at 60 of abduction by 5 ± 5 , 7 ± 5 , and 9 ± 7 , and external rotation at 60 of abduction by 7 ± 7 , 15 ± 10 , and 18 ± 8 . According to Liu et al’s report,¹² a medial shift of 17 mm or more may reduce the moment arm. Based on our results and those of Liu et al,¹² a medial shift of 17 mm or more should be avoided from the functional point of view because it reduces both the moment arm and the range of shoulder motion. Although the surgical procedure should be determined on a case-by-case basis, we should be aware that the tear closure could be achieved by the medial advancement of the attachment site at the cost of various degrees of impairment of the shoulder function and motion.

Many biomechanical studies have already clarified that the use of transosseous equivalent repair for rotator cuff repair was



Fig. 4. Schematic drawing of the abduction restriction mechanism. The more medially the insertion site of the tendon is shifted, the earlier the physiological internal impingement occurs and the less the abduction is achieved.

superior to other techniques such as the single- or dual-row technique in terms of contact area or pressure between the rotator cuff tendon and the footprint, and the initial pull-out strength.^{14,15} Using this technique, we are able to expect a greater initial fixation strength. However, the tendon itself is inherently elastic. If we fix the torn tendon by the transosseous equivalent repair technique, the tendon may lose its inherent elasticity due to the crossover of the strong sutures. We need the initial strong fixation to avoid pull-out failure after surgery. However, the fixation is required only for the first few months. In fact, our recent study demonstrated that the rotator cuff tendon became stiffer after arthroscopic rotator cuff repair, especially transosseous equivalent repair. The strain of the supraspinatus tendon was measured using ultrasound elastography. Results showed that the superficial layer of the supraspinatus tendon was stiffer after transosseous equivalent repair than the contralateral side at the final follow up (mean, 14 months).¹⁶ In addition, our finite-element analysis revealed that a high-stress concentration was observed around the insertion sites of the medial row threads.¹⁷ Based on these results, we recommend that surgeons should pay attention to the quality of the greater tuberosity or cuff tendon, especially at the medial row area when applying the transosseous equivalent technique. The tying of the medial knots during transosseous equivalent repair is clinically controversial. There are several biomechanical reports demonstrating biomechanical improvement (ultimate load, contact pressure, and stiffness) by tying the medial row of a transosseous equivalent repair.^{18,19} Tamboli et al²⁰ investigated the effects of bite-size horizontal mattress stitch: whereas a 4-mm bite fixed the tendon more tightly but at the cost of decreased ultimate strength, a 10-mm bite conveyed greater ultimate strength but with increased gap and strain. They concluded that for transosseous equivalent repair, large stitches are beneficial because the repaired tendon has a higher strength, and the slightly mobile medial knot can be tightened by lateral fixation.

In conclusion, we believe that it would be beneficial for surgeons to obtain basic knowledge about the shoulder biomechanics of their patients and to know the biomechanical effects or advantages and disadvantages of surgical procedures.

Conflicts of interest

All contributing authors declare no conflicts of interest.

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